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(54) **CONTROL SCHEME FOR AN EVAPORATOR OPERATING AT CONDITIONS APPROACHING THERMODYNAMIC LIMITS**

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(58) **Field of Classification Search** .... 122/1 B, 122/31.1, 406.1; 165/104.11–104.19
See application file for complete search history.

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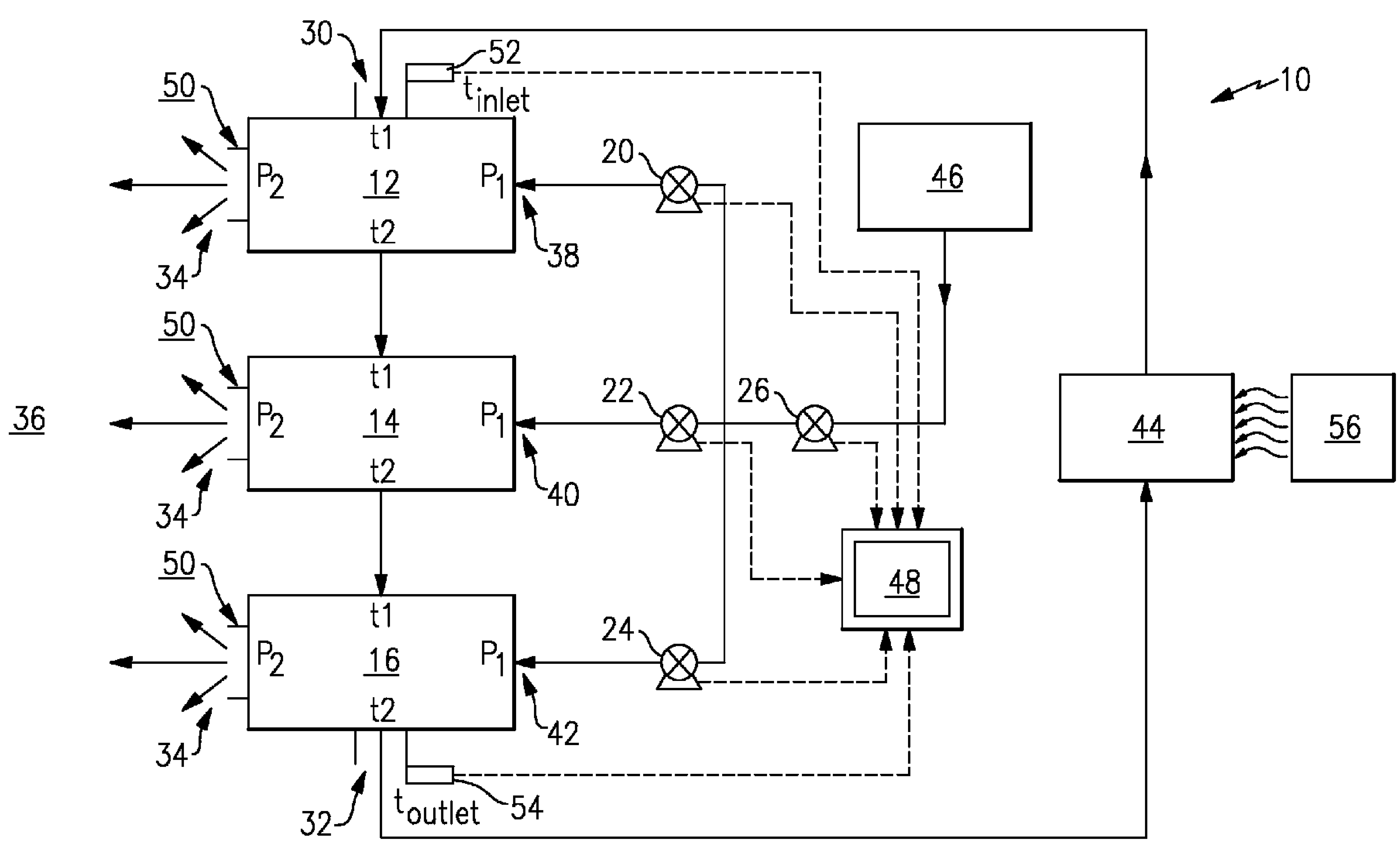
(57) **ABSTRACT**

A heat exchanger assembly includes a plurality of evaporative heat exchangers that are selectively feed evaporant to tailor operation to current heat load in order to maintain operation in thermodynamically extreme operating conditions.

17 Claims, 2 Drawing Sheets



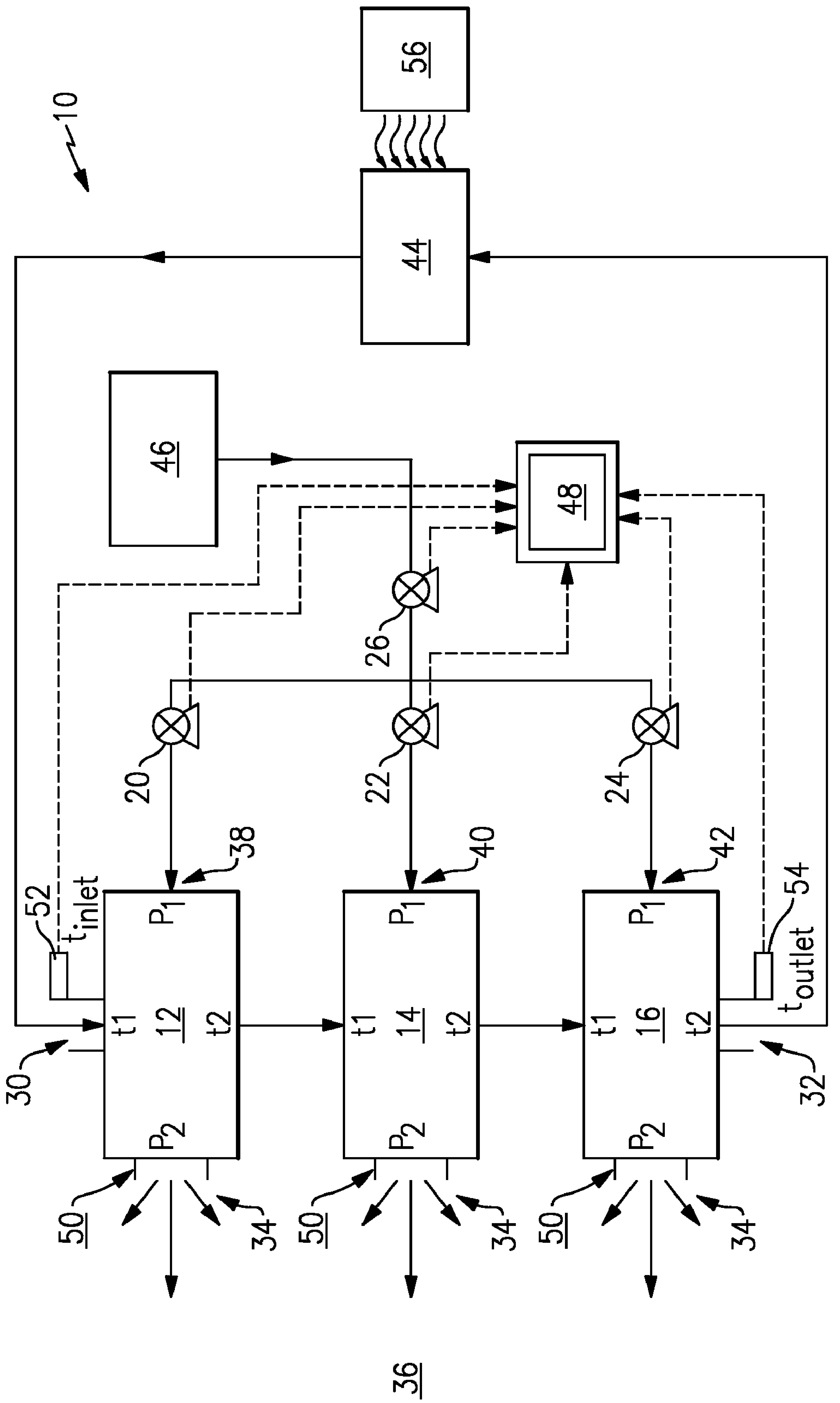

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FIG.1

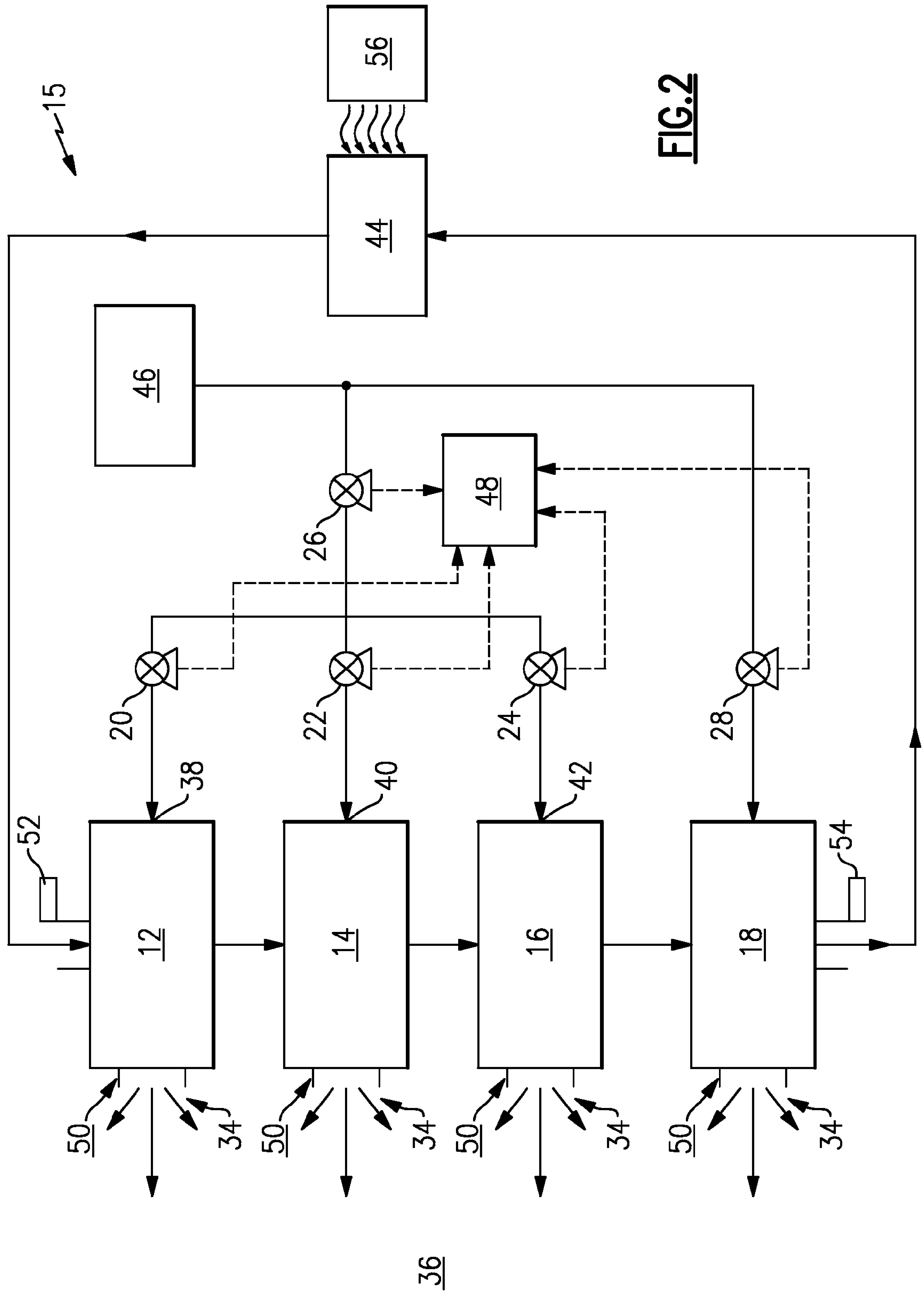

FIG.2

CONTROL SCHEME FOR AN EVAPORATOR OPERATING AT CONDITIONS APPROACHING THERMODYNAMIC LIMITS

BACKGROUND OF THE INVENTION

This invention generally relates to a method of controlling an evaporative heat exchanger. More particularly, this invention relates to a control scheme for operating an evaporative heat exchanger that exhausts to space vacuum.

Evaporative heat exchangers are utilized in applications where a conventional radiator cannot be utilized. An evaporative heat exchanger includes a cooling medium that accepts heat from another system and exhausts that heat to an ambient environment. Water is a very efficient cooling medium with a latent heat of 1000 BTU/lb (2326.000 J/kg). The favorable latent heat to weight ratio makes water a suitable choice for use in vehicles operating in extreme conditions with restrictive space and weight requirements.

The conditions in which evaporative heat exchangers are utilized in a space vacuum are at the extreme thermodynamic conditions for water. Slight changes in pressure and temperature can result in freezing of water within the evaporator. For this reason great care must be taken to maintain operation of the evaporative heat exchanger within desired performance ranges.

Accordingly, it is desirable to design and develop a method and device for adapting evaporative heat exchanger operation to current operating conditions to maintain desired performance.

SUMMARY OF THE INVENTION

The example heat exchanger assembly includes a plurality of evaporative heat exchangers that are selectively fed evaporant to tailor operation to current heat load in order to maintain operation in thermodynamically extreme conditions.

An example evaporative heat exchange assembly includes three evaporative heat exchangers into which is fed a heat transfer medium that carries heat from a heat generating system to an inlet. Heat rejected from the heat transfer medium is accepted by an evaporant feed separately to each of the evaporative heat exchangers. The evaporant enters each of the heat exchangers in a liquid form and vaporizes upon encountering heat given off by the heat transfer medium and is exhausted into an ambient environment.

The example heat exchanger assembly operates in the vacuum of space. The operating environment in the vacuum of space is at or near the triple point of water. At the temperatures expected during operation, water will freeze at pressures below 0.089 psia (613.6 Pa). Therefore, pressures within each of the heat exchangers must be kept above such a pressure to prevent freezing.

The temperature or heat load into the heat exchanger assembly varies during operation. Incoming heat transfer fluid at lower temperatures will not vaporize evaporant at levels encountered with higher temperatures. The resulting reduction in vaporized evaporant reduces pressure within each of the heat exchangers The example system accommodates such temperature fluctuations by tailoring heat load capacity such that pressure within each of the heat exchangers remains above the triple point pressure.

Accordingly, the example disclosed system tailors operation to provide reliable vaporization of liquid evaporant near thermodynamic limits.

These and other features of the present invention can be best understood from the following specification and drawings, the following of which is a brief description.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic view of an example evaporative heat exchange assembly.

FIG. **2** is a schematic view of another example evaporative heat exchange assembly.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. **1**, an example evaporative heat exchange assembly **10** includes three evaporative heat exchangers **12**, **14**, and **16** into which is fed a heat transfer medium **44** that carries heat from a heat generating system **56** to an inlet **30** of the assembly **10**. The heat transfer medium **44** flows into the inlet **30** and rejects heat to emerge from an outlet **32** at a lower temperature. The heat rejected from the heat transfer medium **44** is accepted by an evaporant **46** fed separately to each of the evaporative heat exchangers **12**, **14** and **16**. The evaporant **46** enters each of the heat exchangers **12**, **14** and **16** in a liquid form and vaporizes upon encountering heat given off by the heat transfer medium **44**. The vaporized evaporant **46** is exhausted into an ambient environment **36**.

The example assembly **10** operates where the ambient environment **36** is at or near the vacuum of space. The example evaporant **46** is water as it is a weight efficient evaporant with a latent heat of 1000 BTU/lb (2326.000 J/kg). In vehicles and devices that operate in such extreme environments, weight and space must be allocated in the most efficient manner. Therefore the favorable latent heat to weight properties of water provides the desired efficiencies. However, the operating environment is at or near the triple point of water with temperatures at the relatively low temperature of around 32-36 F.° (0-2 C.°), with pressures approaching zero. At the example operating temperatures water will freeze at pressures below 0.089 psia. For this reason, pressures within each of the heat exchangers **12**, **14** and **16** must be kept above such a pressure to prevent freezing.

Liquid water evaporant **46** entering each of the heat exchangers **12**, **14**, and **16** is vaporized by heat from the heat transfer medium **44**. Each of the heat exchangers **12**, **14**, **16** provides for expansion of the vaporized evaporant to maintain a desired pressure above the triple point pressure. The vapor is then exhausted through exhaust ports **50** as water vapor **34**. The increase in pressure caused by the vaporization of the water evaporant is utilized to maintain pressures above the triple point pressure that causes water to freeze.

As appreciated, the temperature or heat load into the heat exchanger assembly **10** varies during operation. Incoming heat transfer fluid **44** at lower temperatures will not vaporize evaporant **46** at levels encountered with higher heat transfer medium temperatures. The resulting reduction in vaporized evaporant additionally reduces pressure within each of the heat exchangers **12**, **14**, **16**. In the environment in which the example system operates, such a reduction in pressure can result in freezing of liquid evaporant within the heat exchangers **12**, **14**, and **16**.

The example system accommodates such temperature fluctuations by tailoring heat load capacity such that pressure within each of the heat exchangers remains above the triple point pressure. Heat load capacity is controlled by adjusting the flow of water evaporant **46** separately to each of the heat exchangers **12**, **14**, **16** such that the vaporization of the water evaporant produces the desired pressures at each of the outlets **50**.

The assembly **10** includes valves **20**, **22**, and **24** selectively actuated by a controller **48** to control water evaporant **46** flow to each corresponding heat exchanger **12**, **14**, **16**. An inlet temperature sensor **52** communicates temperature information indicative of the temperature of incoming heat transfer medium **44**. An outlet temperature sensor **54** communicates information indicative of outlet temperature of the heat transfer medium. The valves **20**, **22**, and **24** feed evaporant through a variable control valve **26**.

The heat exchangers **12**, **14**, and **16** are orientated to receive the heat transfer medium in series. Heat transfer medium from the first heat exchanger **12** enters the second heat exchanger **14**, which in turn enters the third heat exchanger **16**. Combining the heat exchangers **12**, **14**, **16** in series results in an overall increase in turndown capacity. In the example heat exchanger assembly, each of the evaporative heat exchangers **12**, **14**, **16** operate at a turndown range of 1.5:1. Combining the three provides a turndown range of 3.38:1. ((1.5*1.5*1.5) =3.38:1). When less turndown range is required due to lower temperatures of the heat transfer medium **44**, one or a combination of the heat exchangers **12**, **14**, **16** is deactivated by closing the corresponding one of the control valves **20**, **22**, **24**. Further, each of the heat exchangers **12**, **14** and **16** can provide different turndown ranges that when operated together, or in various combinations tailor heat turndown to current conditions.

Before one of the heat exchangers **12**, **14**, and **16** are deactivated, the variable control valve **26** reduces flow to the currently active heat exchangers **12**, **14**, **16**. When the reduction in evaporant flow is not sufficient to tailor operation of the heat exchanger assembly **10** to the current temperature of the incoming heat transfer medium **44**, one or a combination of the heat exchangers **12**, **14**, and **16** are deactivated. In the disclosed example, the third heat exchanger **16** is deactivated by closing the control valve **24**. Closing the control valve **24** stops the flow of evaporant **46** to the third heat exchanger **16**. Accordingly, the turndown capacity is reduced. Heat transfer medium **44** still flows through the third heat exchanger **16**, but no heat transfer takes place.

Operation continues at the reduced heat turndown capacity that vaporizes evaporant at levels corresponding to the reduced volume of the heat exchanger assembly **10** to maintain pressure above the triple point pressures. Further reductions in heat transfer medium temperatures are accommodated by deactivating the second heat exchanger **14** by closing off the control valve **22**. The resulting reductions in heat turndown range tailors operation to maintain pressure within each of the evaporative heat exchangers **12**, **14**, **16** above a pressure that would cause freezing of the water evaporant.

The heat exchangers **12**, **14**, and **16** can be activated and deactivated in any combination to tailor the heat turndown range to current conditions. The first heat exchanger **12** and the second heat exchanger can be operated together with the third heat exchanger **16** turned off. Because each of the heat exchangers **12**, **14**, and **16** are independently controlled by the corresponding control valve **20**, **22**, and **24**, many combinations of heat exchanger operation can be implanted depending on current operating conditions. Other combinations of the heat exchangers can be operated by closing off one of the corresponding control valves **20**, **22**, and **24**.

Referring to FIG. **2**, another example heat exchange assembly **15** includes a fourth evaporative heat exchanger **18** that receives evaporant through a second variable control valve **28**. In operation, the first, second and third evaporative heat exchangers **12**, **14**, and **16** are selectively feed liquid water evaporant **46** based on the inlet temperature of the heat transfer medium.

The fourth heat exchanger **18** provides a final turndown or temperature reduction. The fourth heat exchanger **18** reduces heat transport fluid outlet temperature to a fixed lower value. Because, the fourth heat exchanger **18** encounters a substantially constant heat load there is little temperature variation and the potential of freeze-up is mitigated. Selectively deactivating one of the first, second and third heat exchangers **12**, **14**, **16** provides an output of heat transport fluid **44** at a substantially constant temperature regardless of the temperature at the inlet **30**. Therefore, the fourth heat exchanger **18** is not exposed to the range of temperatures that the first three heat exchangers **12**, **14**, **16** encounters. The second variable control valve **28** provides a sufficient range of evaporant flow to control any small fluctuation in temperature that may occur.

In the disclosed example, the heat transfer medium is also water as water is an efficient heat transfer medium relative to weight. However, other heat transfer mediums may be utilized as are dictated and desired by application specific requirements. Further, the example evaporant is water. The example system is specifically designed to take advantage of the favorable latent heat to weight properties of water. The example ambient conditions expose water to the thermodynamic extremes where small changes can result in liquid water vaporizing or freezing. Accordingly, the example disclosed system tailors operation to provide reliable vaporization of liquid water near triple point pressures.

Although a preferred embodiment of this invention has been disclosed, a worker of ordinary skill in this art would recognize that certain modifications would come within the scope of this invention. For that reason, the following claims should be studied to determine the true scope and content of this invention.

What is claimed is:

1. A method of controlling an evaporative heat exchanger assembly comprising the steps of:

a) directing a heat carrying medium through a plurality of evaporative heat exchangers in series;

b) determining a temperature of the heat carrying medium at an inlet to the plurality of evaporative heat exchangers;

c) directing a liquid evaporant separately through each of the evaporative heat exchangers that vaporizes while accepting heat from the heat carrying medium;

d) exhausting the vaporized evaporant from each active one of the plurality of evaporative heat exchangers; and

e) selectively controlling evaporant flow to each of the plurality of evaporative heat exchangers responsive to the temperature of the heat carrying medium at the inlet to mitigate potential freezing of the evaporant within each of the plurality of evaporative heat exchangers.

2. The method as recited in claim **1**, wherein the step of selectively controlling each of the plurality of evaporative heat exchangers includes the step of stopping evaporant flow to at least one of the evaporative heat exchangers.

3. The method as recited in claim **1**, wherein the step of exhausting evaporant includes exhausting evaporant to an ambient environment, where the ambient environment is at a condition in which the evaporant freezes.

4. The method as recited in claim **1**, wherein each of the evaporative heat exchangers include an exhaust opening of a fixed non-changeable size.

5. The method as recited in claim 1, wherein the evaporative heat exchanger assembly includes three evaporative heat exchangers that are each separately feed liquid evaporant.

6. The method as recited in claim 5, wherein controlling evaporant flow includes shutting off flow to one of the three evaporative heat exchangers and adjusting a flow rate of evaporant based in the temperature of incoming heat transport fluid at the inlet to produce a desired output temperature of the heat transfer fluid.

7. The method as recited in claim 5, including a fourth evaporative heat exchanger separately controllable from the three evaporators and receiving heat transfer medium once flowed through the three evaporative heat exchangers to provide a further desired heat load turndown.

8. The method as recited in claim 7, wherein evaporant flow to the fourth evaporative heat exchanger is adjusted based on the inlet temperature.

9. The method as recited in claim 1, including a controller for selectively actuating control valves associated with each of the plurality of evaporative heat exchangers to control the flow of liquid evaporant.

10. The method as recited in claim 1, wherein at least one of the plurality of evaporative heat exchangers is of a different capacity than any of the other of the plurality of evaporative heat exchangers.

11. An evaporative heat exchanger assembly comprising:

a plurality of evaporative heat exchanger cores each including an evaporant inlet, an evaporant exhaust, and an inlet for receiving a heat transfer medium, wherein subsequent ones of the evaporative heat exchangers receive heat transfer medium from a preceding one of the plurality of evaporative heat exchangers such that the heat transfer medium flows through each of the plurality of heat exchangers in series;

an evaporant control valve associated with each of the plurality of heat exchangers for controlling evaporant flow;

a variable control valve for controlling evaporant flow to each of the evaporant control valves;

an inlet temperature sensor disposed at the inlet for receiving the heat transfer medium; and

a controller for actuating the evaporant control valves and the variable control valve responsive to a temperature of the heat transfer medium measured by the inlet temperature sensor to maintain a desired pressure at the evaporant exhaust of each of the plurality of evaporative heat exchanger to prevent freezing of the evaporant flow within each of the plurality of evaporative heat exchangers.

12. The assembly as recited in claim 11, wherein each of the evaporative heat exchangers includes a heat turndown ratio that are combined to provide an assembly turndown ratio.

13. The assembly as recited in claim 12, wherein the assembly turndown ratio is varied by controlling evaporant flow to each of the evaporative heat exchangers.

14. The assembly as recited in claim 11, including an outlet temperature sensor disposed at an outlet of the heat transfer medium for communicating a temperature of the heat transfer medium to the controller.

15. The assembly as recited in claim 11, wherein each of the evaporative heat exchangers exhausts evaporant to an ambient environment, wherein the ambient environment comprises conditions that causes the evaporant to freeze.

16. The assembly as recited in claim 15, wherein the evaporant comprises water.

17. The assembly as recited in claim 11, wherein at least one of the plurality of evaporative heat exchanger cores is of a different capacity than any of the other of the plurality of evaporative heat exchanger cores.

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